N103601

N-103601
Ha -8
H-5.8

DEVELOPMENT OF WATER RECYCLING DEVICE WITH SPECIAL REFERENCE TO SPACE APPLICATION*

N64 81095
Code NONE

By

J. J. Konikoff
and
L. W. Reynolds

Presented at 32nd Annual Meeting
Aerospace Medical Association, Chicago, Ill.
April 24-27, 1961

*This research is under the support of the office of Life Sciences, National Aeronautics and Space Administration, Contract No. NASw 127.

Space Sciences Laboratory
Missile and Space Vehicle Department
GENERAL ELECTRIC COMPANY
Philadelphia, Pa.

I. INTRODUCTION

Several well known methods may be employed in any attempt to recover potable water from metabolic wastes. Simple vacuum distillation is the most straightforward approach. Other techniques include lyophilization and ion exchange.

Vacuum distillation is acceptable with respect to the flow rate and energy input, but the distillate is contaminated with ammonia and volatile organic compounds. These substances impart a foul urine-like odor to the distillate. (Ref. 6)

Lyophilization yields essentially the same product as vacuum distillation, but the slower flow rate makes this approach even more objectionable. Odorless water can be obtained by the use of ion exchange resins, however, a very large quantity of resin is necessary because of the high concentration of solutes in whole urine. Further, the resin requires regeneration before it can be used again. (Ref. 10)

Logically then, vacuum distillation should be a part of any system used to recover potable water from urine and feces. However, some system must be incorporated for the destruction or modification of ammonia and volatile organic compounds.

The oxidation of ammonia by a heated Platinum or Platinum-10 percent Rhodium catalyst is well know. (Ref. 1-9) Temperatures necessary for this reaction range from 250C (Ref. 3) to 1300C (Ref. 8). The best catalyst (Ref. 1-3) is a 10 percent Rhodium alloy of Platinum because the rate of

ammonia conversion is highest and the alloy is not poisoned as rapidly as pure Platinum. The conversion rate is increased by the use of oxygen (air) in the system (Ref. 9). (Studies conducted in this lab indicate that a small quantity of air is necessary for the complete oxidation of ammonia.) Poisoning of the catalyst (Ref. 3) is reported to be caused by the adsorption of hydrogen on the catalyst. However, the catalyst can be restored by treating it with an oxidizing agent (Ref. 4). The loss of catalyst (Ref. 2) has been estimated to be 0.15 g/ton HNO_3 for pure Platinum and 0.05 g/ton HNO_3 for the Platinum Rhodium alloy. Therefore, this alloy seems to possess excellent characteristics as regards catalytic activity and resistance to poisoning.

Konikoff and Bengson (Ref. 7) have previously described a system which utilizes vacuum distillation coupled with the catalytic oxidation of volatile components.

This paper addresses itself to a design modification, energy requirements and biological testing of the recovered water.

II. EXPERIMENTAL

A. APPARATUS DESIGN & OPERATIONS

Fig. 1 is a photograph of the original apparatus used for the recovery of water from urine. A 30 inch mullite tube which contains the catalyst is heated by a large inefficient furnace. This design does not easily lend itself to accurate measurement of energy requirements.

A more recent, compact design is shown in Fig. 2. The heating unit, which consists of a 12 inch piece of helically coiled Kanthal wire (#20), is wrapped around the middle of a 6 inch mullite tube. The wire is covered with a suitable cement and a rheostat is used to control the temperature. The temperature is measured by means of a thermocouple imbedded in 10-18 g of catalyst which is packed so that it completely occludes the orifice of the mullite tube. The entire unit is fitted into a vacuum distillation train.

The operating parameters for this device are as follows:

Temp. catalyst	1100°C
Vacuum	60 mm Hg
Temp. urine	40°C
Flow rate	180 ml/hr
Air feed rate	0.05 - 0.2 CFH
Weight of catalyst	10 - 18 g

Recent studies indicate that these operating conditions are changed considerably by altering the geometry of the catalyst. When the catalyst is separated, as in Fig. [3]. less catalyst is needed and potable H_2O is obtained at the comparatively low temperature of 800°C. Further studies of catalyst geometry as a function of operating conditions are presently

being carried out in this laboratory.

Water recovered by this method was submitted for complete chemical analyses. Table I shows a comparison of potable water with a condensate obtained by simple vacuum distillation.

A test for bacteriological contamination was conducted since it was known that these organisms were present in the vapor. Table I-a shows that these cells were destroyed when the vapor passed through the region of the heated catalyst.

B. Determination of pH and Total Solids as a Function of Temperature

Water recovered by this technique varied from 3.5 to 9.8 in pH. Although this variation in pH range has no effect upon the potability of the product, experiments were planned to test the effects of temperature. The flow rate and catalyst mass were maintained constant and the temperature was varied. The geometric configuration of the 15 g catalyst was a solid cylindrical mass. Samples of the condensate at each different temperature setting were checked on a pH meter.

The pH of each sample was plotted against the temperature as seen in Figure 4. The pH varied from 3.9 to 9.1, the temperature from 1025°C to 1115°C. Hence, a change in temperature of only 90°C was observed to produce a variation of about 5 pH units. These data indicate that if a relatively constant pH, i.e., 7.0 ± 1, is to be consistently obtained, the temperature of the catalyst must be minutely controlled.

The total solid content of the recovered water was determined as an extension of the above comparison of pH. Figure 5 shows that the total solid value decreased as the temperature increased. At normal operating temperatures of 1000 to 1100°C a value of less than 100 ppm was obtained.

Figure 6 shows some of the relationships of pH and temperature when the geometry and mass of the catalyst is changed.

A solid mass of 10 g of catalyst gave pH values above 9.3. Potable water was obtained from 17.5 g of catalyst from 1275°C to about 1150°C.

Next, the catalyst mass was increased to 25 g and a potable distillate was obtained in the range of 1200°C to 1060°C.

The last curve shows that potable water was recovered at a temperature as low as 820°C although the mass of the catalyst was decreased to 7.5 g. This is a function of a change in the geometry of the catalyst. In this experiment the platinum gauze screens were separated into three (3) separate zones. (See Fig. 3)

These data indicate the dramatic effect of catalyst geometry in regard to the development of optimal operating conditions.

C. Energy Requirement

The recovery of potable water by this method involves distillation, catalytic oxidation and condensation. Energy requirements then, must be considered as a function of these three factors.

Energy necessary for the catalytic oxidation was determined by recording the change in temperature of the catalyst ($\Delta t = 40^{\circ}C$) at a constant flow rate ($\omega = 2$ ml/min). The weight of the catalyst was 10 g.

Therefore since,

$$Q = MC_p \Delta t$$

where,

Q = energy

C_p = specific heat of platinum

Then,

$$Q_1 = 10 \text{ g} \times 0.39 \text{ cal/g} \times 40^{\circ}C$$

$$Q_1 = 15.6 \text{ cal/min.}$$

or,

$$Q_1 = 936 \text{ cal/hr}$$

This represents the heat input necessary for the oxidation of the volatile components contained in 120 ml of urine.

Since the average daily output of urine by one man is approximately 1500 ml, the total energy requirement for a one-man day is

$$Q_C + 936 \times \frac{1500}{120} = 11700 \text{ cal/day}$$

In engineering units this is 1.3×10^{-2} Kwh.

The sensible and latent heat required to vaporize the urine must be added to the calculation above. Assuming that urine is essentially water this requirement is about 277.2 Kcal/lb.

Hence,

$$Q_D = 3.3 \text{ lb/day} \times 277.2 \text{ Kcal/lb.}$$

$$Q_D = 914.8 \text{ Kcal/day}$$

Thus, the total input/day is

$$Q_T = Q_D + Q_C = 914.8 + 11.7$$

or,

$$Q_T = 926.5 \text{ Kcal/day or } 3706 \text{ BTU}$$

Recovery of energy from the condensation of the vapor has not yet been given adequate consideration.

D. Biological Tests

The Department of Biology at Bryn Mawr College maintained a large colony of rats for the purpose of observing any deleterious effects which might be caused by long term feeding with water recovered from urine. A controlled colony was also maintained for comparison.

Pregnant rats delivered normal litters on schedule with no difference as to number, size or growth rate. No anomalies were observed in fur color or size of organs. The appetite, volume of water consumed, and appearance of excrete did not vary from the control groups.

Sex organs, liver, lymph nodes, adrenal spleen, thymus, and kidney were examined in order to detect biological changes. No anomalies were observed.

Capt. R. A. Bosee, MC, USN, Director of ACEL, volunteered to be the first human to subsist entirely on water recovered by this method. All urine was collected each day and 95% of the water present was recovered. Water lost thru respiration, etc., was made up by processing urine obtained from other laboratory personnel. This experiment continued for 6 days, and Capt. Bosee reported (Ref. 5) no ill effects.

Also, normal values were reported by ACEL for various biochemical examinations of his urine, blood, etc.

III. DISCUSSION

Data presented in this paper show that potable water has been obtained over a broad range of operating parameters. However, more experimentation is required in order to refine the system so that it will function perfectly on an absolute minimum of energy. Catalyst geometry may well provide part of the answer to the question of lowering over-all energy requirements. Conservation of energy by redistribution or recovery of energy for other purposes would also lower energy requirements if a successful method could be devised.

Chemical and biological tests have shown that this water is potable and does not produce any deleterious effect on biological specimens even after long periods of recycling. These tests should be augmented by an analysis for possible organic compounds that result from the degradation of the volatile organic compounds present in urine. These volatile compounds are either altered or completely destroyed since the recovered water does not possess a foul odor and is tasteless. At any rate, it is certainly advisable to determine the fate of these compounds.

IV. SUMMARY

A method is described that successfully allows the recovery of potable water from metabolic wastes. Urine is vacuum distilled and the vapor is passed over a heated catalyst. Temperature, catalyst geometry, and energy requirements are discussed.

The results of chemical analyses and biological testing are presented.

BIBLIOGRAPHY

1. Adadurov, E., J. Appl. Chem. USSR, 9, 1221-4, 1936
2. Adadurov, E., J. Phys. Chem. USSR, 9, 592-7, 1937
3. Adadurov, E., J. Chem. Ind. USSR, 14, 831-6, 1937
4. Adadurov, E., J. Chem. Ind. USSR, 14, 738-44, 1937
5. Bosee, R. A. et al 32nd Annual Meeting Aerospace Medical Assoc., April 1961
6. Ingram, W. T., Proc. of Am. Astro. Soc., 4th Annual Mtg. 1950
7. Konikoff, J. J. and Bengson, M. H., GE TIS R60SD341, (1960)
8. Krauss, W., Z. Psysik Chem. B-39, 83-100, 1938
9. Marczewska, K., Roczniki Chem. 23, 406-17, 1949
10. Sendroy, J. and Collison, H. A., Jr., Aerospace Med. 30, 640 (1959)

TABLE I

CHEMICAL ANALYSIS OF CONDENSATE TO POTABILITY

	Urine Only fully treated	Urine & Feces fully treated	Urine & Feces (10B) distilled only
Ammonia as N, ppm	0.10	35	1250
Total Hardness	2	0	1
Chloride, ppm	0.5	2	14
pH	6.8	8.8	10.10
Nitrate as NO_3, ppm	0.05	0.025	0.025
Nitrate as NO_2, ppm	0	0	138
Color units	0	0	7
Phenol, ppm	0.0	0.0	3.25
Odor (intensity)	None	None	Strong Pungent
Total Solids	14	54	168
Phenolphthalein Alk. as $CaCO_3$, ppm	0	20	4670
Methyl Orange Alk. as $CaCO_3$, ppm	2	86	5810
Specific Conduct. (micro-ohms)	3.4	180	1400

TABLE I-A

BIOLOGICAL TEST RESULTS

	Results Period of Incubation			
	24 hrs.		65 hrs.	
	20	37	20	37
Total Number of Bacteria per ml on Agar	15	25	20	29
Presumptive Test (Coliform Group)				
Volume of Sample				
10.0 ml		0/5		0/5
1.0 ml		-		0/5
0.1 ml		-		0/5

REMARKS:

This sample as tested conforms with the bacteriological requirements of the U. S. Public Health Service Drinking Water Standards.

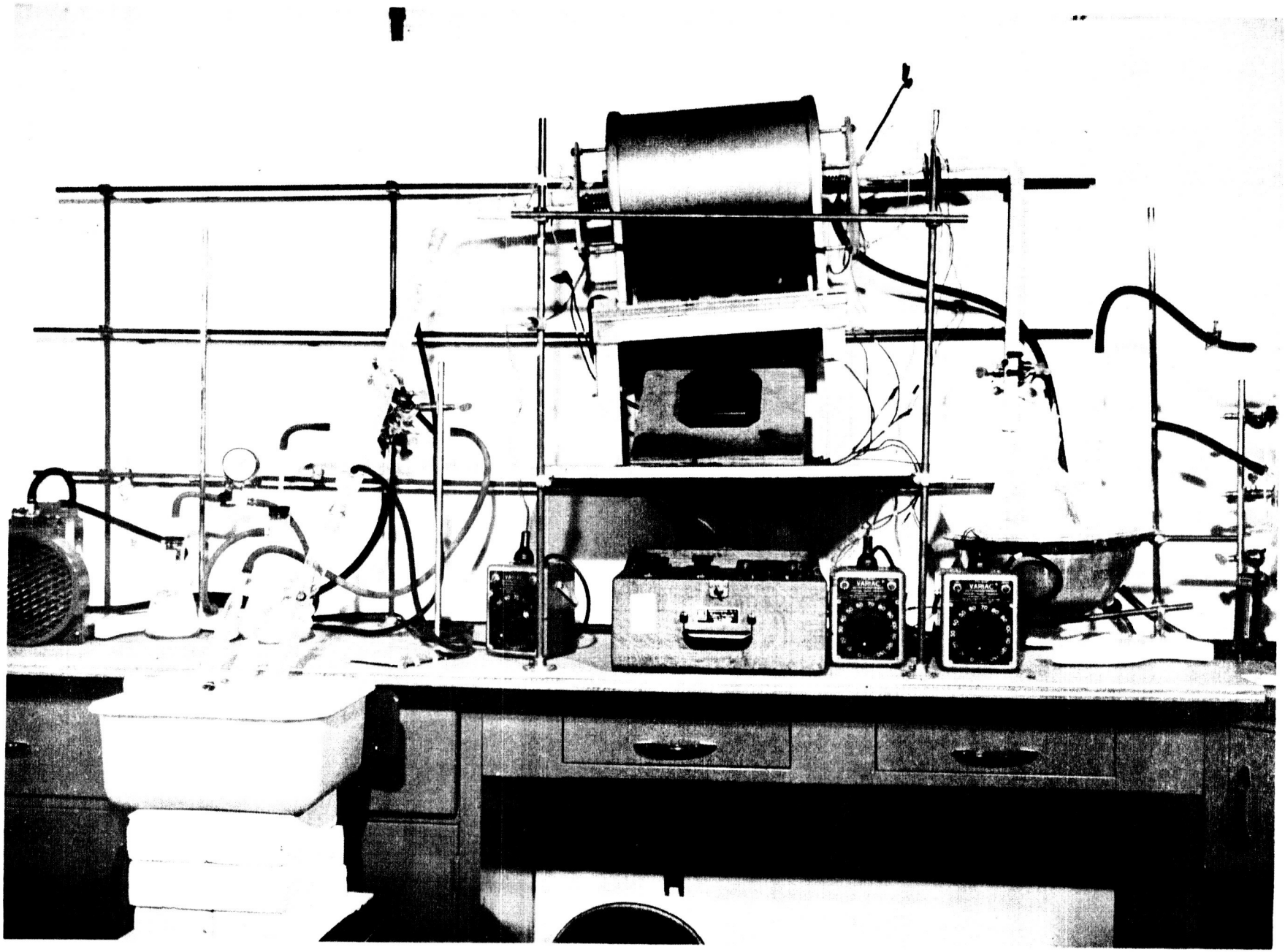

FIGURE 1.

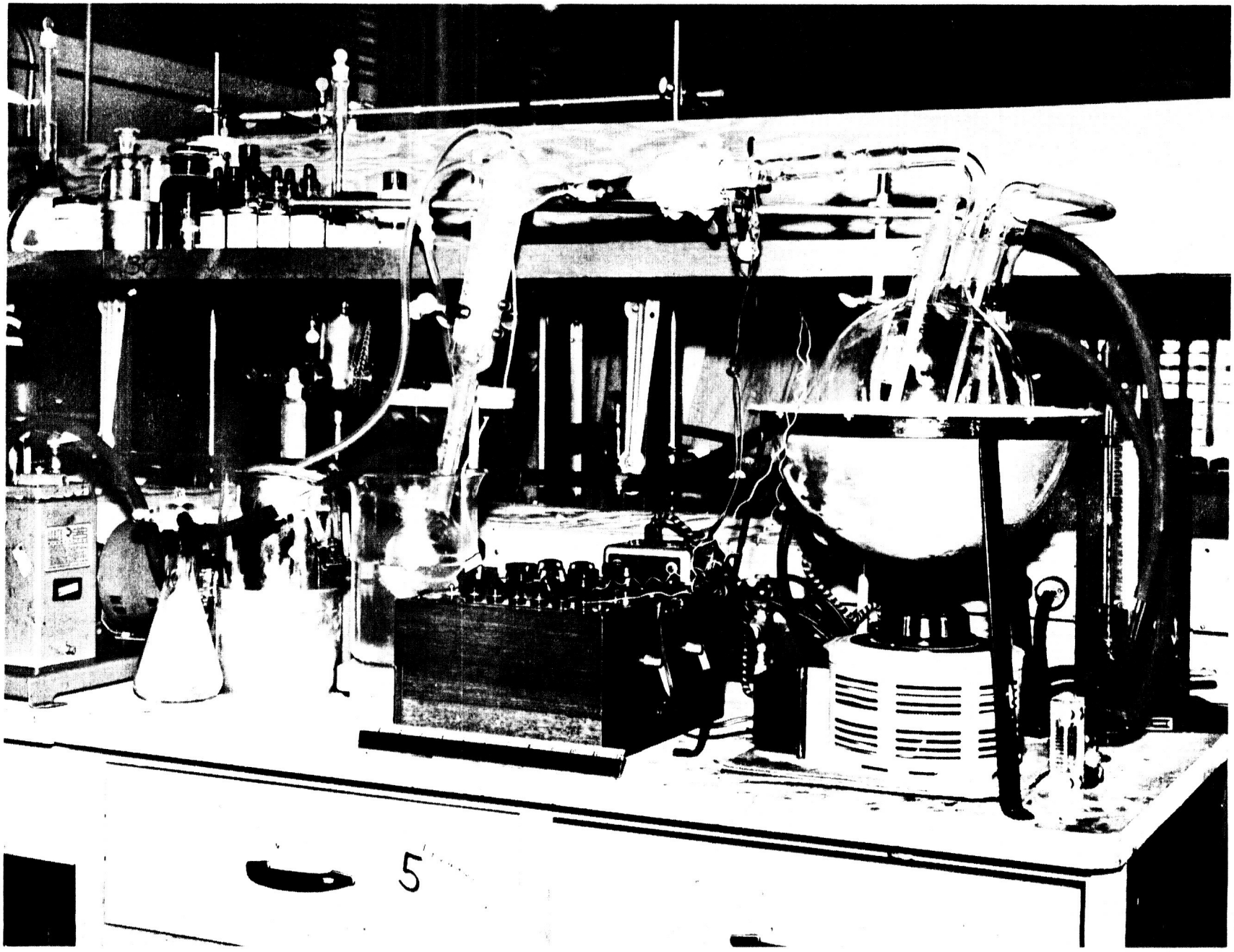

FIGURE 2.

EXAMPLES OF DIFFERENT CATALYST GEOMETRY

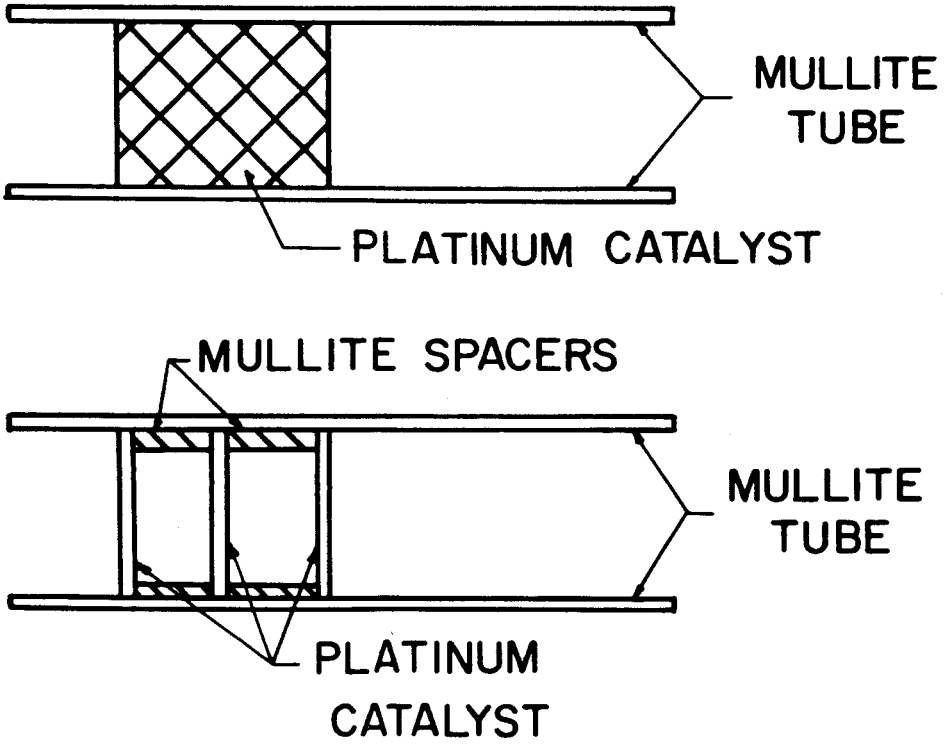

Figure 3

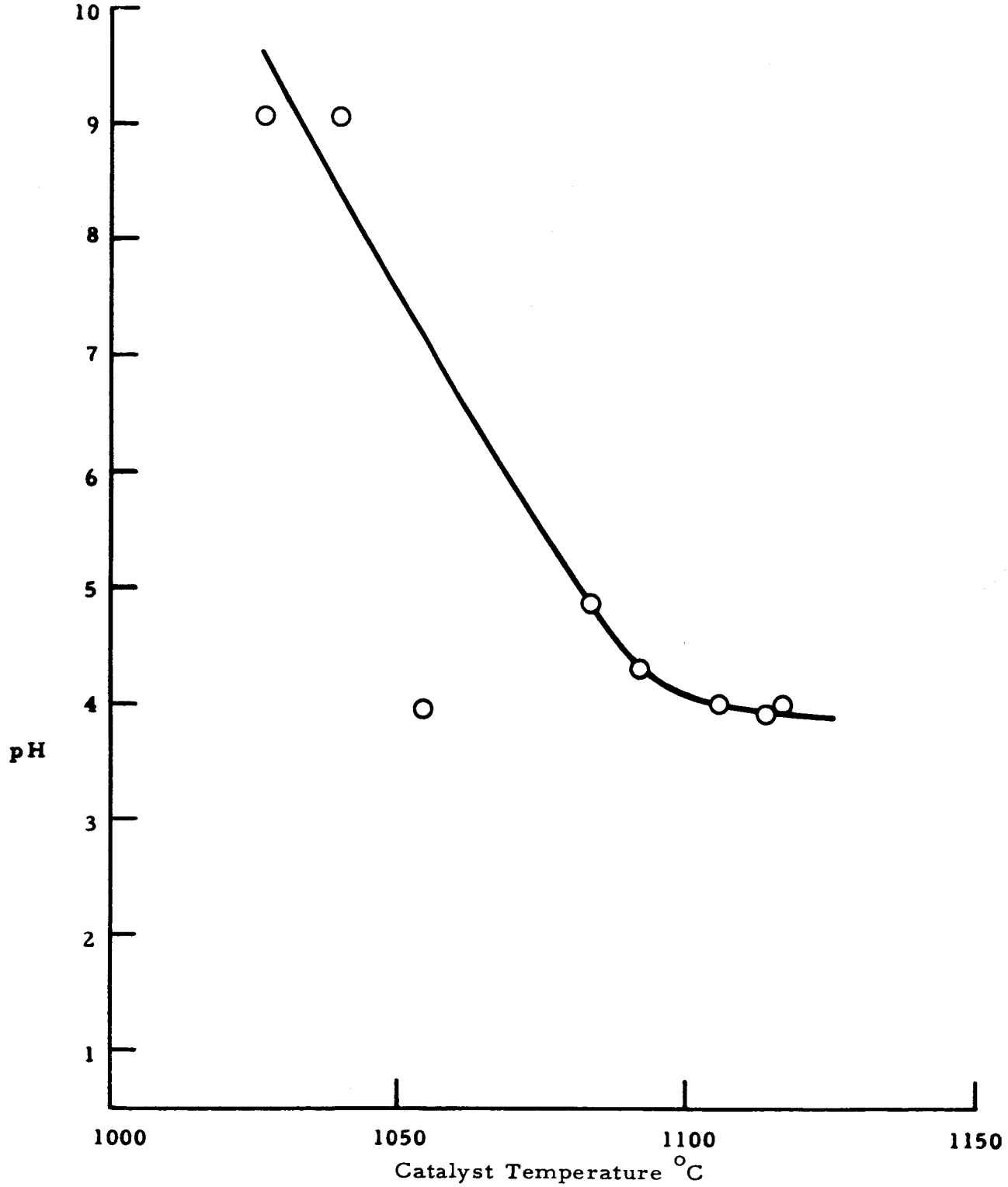

FIGURE 4. Product pH vs Temperature of Catalyst

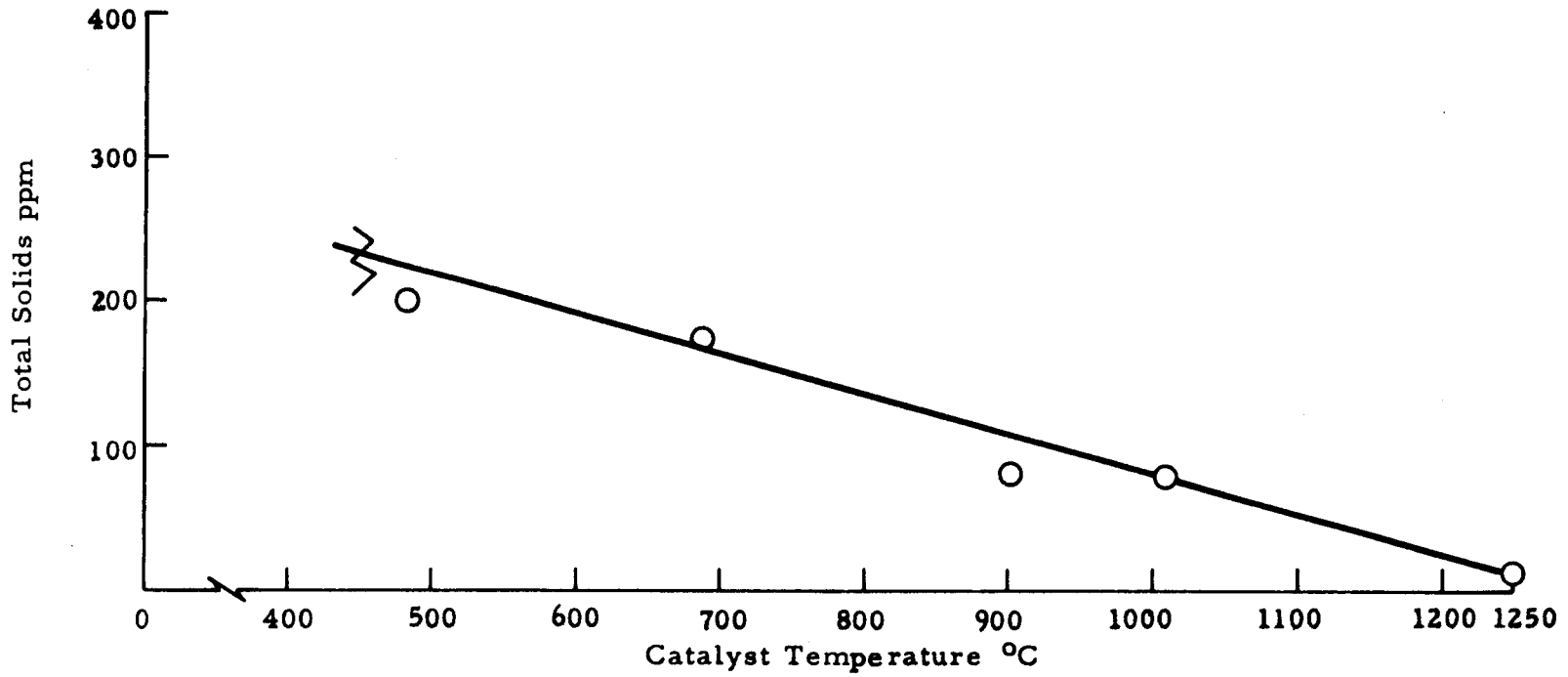

FIGURE 5. Total Solids vs Catalyst Temperature

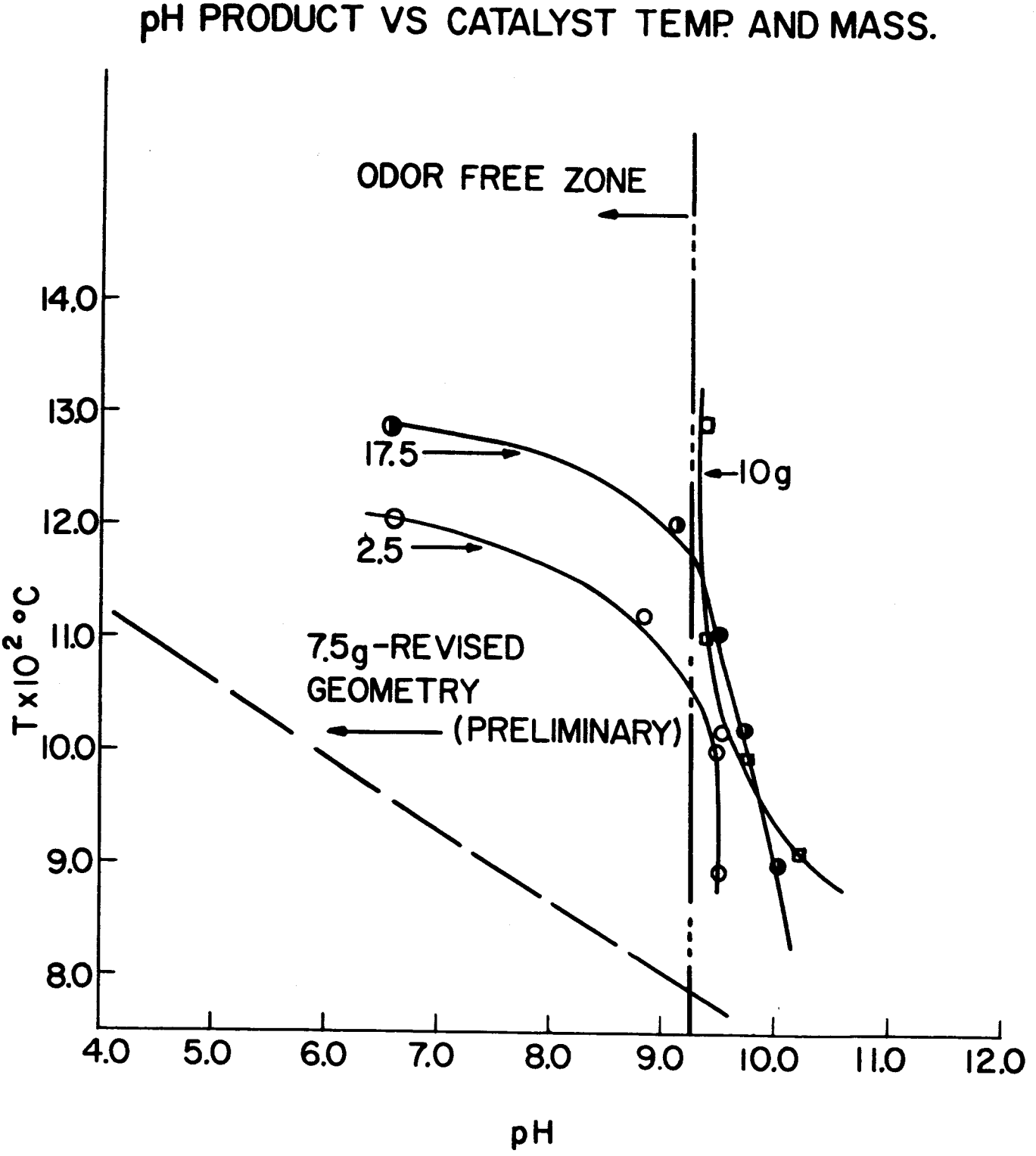
pH PRODUCT VS CATALYST TEMP. AND MASS.
ODOR FREE ZONE
14.0
13.0
12.0
11.0
10.0
9.0
8.0
T x 10² °C
17.5
10g
2.5
7.5g-REVISED
GEOMETRY
(PRELIMINARY)
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
pH

Figure 6